

CURVES OF EQUAL-LOUDNESS FOR OCTAVE-BANDS

G. Jahn

Translation of: "Kurven gleicher Lautstärke für Oktaybandpassrauschen", In: Hochfrequenztechnik und Elektroakustik, vol. 67, no. 6, 1959, pp. 187-89.



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16. Abstract Stimulated by the generally accepted method of Stevens, measurements of the isophons for octave-bands were undertaken by the Electro and Construction Acoustics Division of Dresden University in 1956. At first these were limited to diffuse acoustic field with comparison of octave-bands with middle frequencies; later, through tests on 10 persons, the curves of equal loudness for octave bands of 40 phons in the frontal oncoming plane wave and diffuse acoustic field were determined. It is only in the present article that attention is given to the loudness to which the sound level of a chosen comparison signal should correspond, so that measured curves can be truly identified with a loudness in phons.			
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CURVES OF EQUAL-LOUDNESS FOR OCTAVE-BANDS

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(Communications from the Institute for Electro and
Construction Acoustics of the Dresden Technical
University (Dir. Prof. Dr. W. Reichardt))

(Submitted on September 22, 1958)

I. Introduction

Curves of equal-loudness for sine-tones which can be heard ^{*/187}
binaurally as a frontal oncoming plane wave have been used for
some time. They were measured again recently in a thorough
study by Robinson and Dadson [1]. We have less information
on the course of curves of equal-loudness for octave-bands.
They are important, among other things, in the calculation of
a uniform noise from the measured level-octave-diagram, as in
the method, for example, used by Stevens [2]. Stimulated by
the work of Stevens, measurements of the isophons for octave-
bands were undertaken by the Institute for Electro and Construc-
tion Acoustics of the Dresden Technical University in 1956. At
the start these were limited to the diffuse acoustic field and
involved the comparison of octave-bands with middle frequencies
of between 100 Hz and 9.6 kHz with a third-octave band of 1 kHz,
the sound level of which came to $L = 50$ dB. Later on we deter-
mined by tests on a team of 10 persons the curves of equal-
loudness for octave-bands of 40 phons in the frontal oncoming
plane wave and in the diffuse acoustic field.

The starting point for the reference magnitude of loudness
[3], [4], the sound level of the frontal oncoming 1 kHz sine-
wave, was obtained by a subjective loudness comparison of the
third-octave band (900 1140 Hz) used as comparison signal

with a 1-kHz sine-tone for measurements in the plane wave. In order to be able to apply the results of the measurements in the diffuse acoustic field to the plane oncoming 1 kHz sine-wave, we took advantage of the fact that regardless of the form of the acoustic field in a free field, a specific sound level on the tympanum for a given signal always leads to the identical loudness [5]. Thus, by objective measuring of the sound level in the undisturbed field, as well as in the tympanum, it was possible to determine the sound level of the comparison signal in the diffuse field that corresponds to a loudness of 40 phons.

2. Apparatus for the experiments and method of the investigation

A general circuit diagram of the apparatus is shown in Fig. 1. The third-octave band of about 1 kHz used as comparison signal was, alternately with an octave-band of variable middle frequency, switched on for a period of 1.3 seconds with the aid of an electronic change-over switch to a loud-speaker unit which reflected a diffuse acoustic field in the hall--a plane wave in an area free from reflection. There was a 0.3 second pause between the two signals. The comparison signal remained constant (55, respectively 40 phons) as to level, while the level of the octave-band was constantly varied by 1.3 dB/s by a motor-equipped damping control (5). It was the responsibility of the test subjects to regulate the damping by pressing the key (10) whenever they felt that the octave volume was clearly louder or softer than the comparison signal. Recording of the judgments then followed by means of a level recorder (9) which was placed right in front of the electronic switch. The amount given out by the transmission apparatus right behind the level recorder was also measured and considered in the evaluation

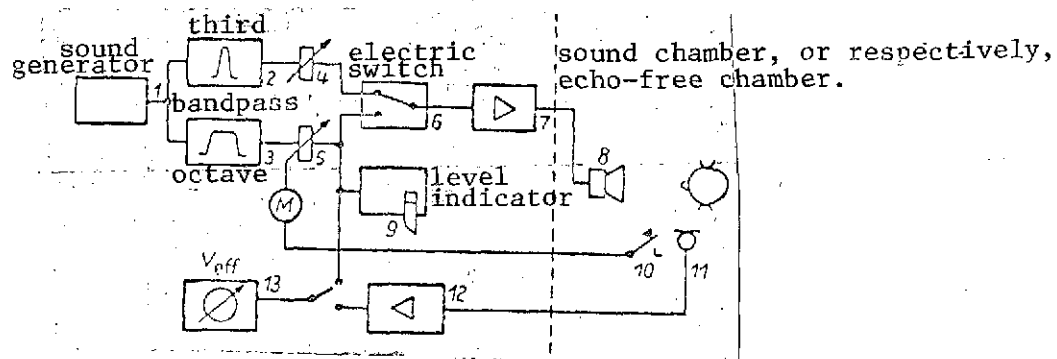


Fig. 1. Apparatus for measurement of the curves of equal-loudness for octave-bands.

of the results. A condenser microphone was available for sound level measurements; it was calibrated both for the plane wave as well as for the diffuse acoustic field. The maximum measuring accuracy of the level measurements came to around 1.5 dB.

The diffuse acoustic field was created by four mounted loudspeakers on the corner sound-walls of a hall in which the resonance time came to from 2 to 3 seconds. The place dependent fluctuations of level within a sphere of 50cm radius around the later measuring place were for frequencies greater than 1 kHz less than 1dB and for lower frequencies less than 1.8 dB. /188

The progressive plane wave was realized with good approximation in the area free from reflection at 3 meters distance from the loud-speaker mounted on one of the walls of the room, which, because of a perforated screen placed before it, could also reflect high frequencies in practically half-spherical form. The level fluctuations dependent on place lay within a sphere around the place of measurement with a 50 cm diameter under 1 dB.

The comparative method chosen was used in this manner for the first time by v. Békésy [6] for audiometric measurements, and is of a boundary. A single measurement took approximately 2 minutes. In order to avoid excessive strain on the persons used in the test, the duration of an experimental series was limited to 25 minutes at most. All measurements were taken twice so that the judgment of the persons participating could be verified. Moreover, while measuring the level of the octave band, the leader of the experiments made intentional changes so as to determine whether the persons tested would find their way back to their first reaction.

The age of the test subjects--generally assistants and students who participated in such tests for the first time--ranged from 20 to 30.

3. 3. The loudness of the third-octave used for comparative purposes.

It was found from the previously mentioned loudness comparison of a 1 kHz sine-tone with a third-octave of around 1 kHz in the plane wave, that the sound level of this from 40 to 60 phons was 2 dB less in loudness than that of the sine-tone must be if both signals are to be felt as equally loud. This corresponds well with results in publications on the band width dependency appraisal of noises by the ear [9], [10].

Objective measurements with a probing microphone of the differences between the sound level in the undisturbed field and the level in the tympanum showed that at 1 kHz, the sound level in the undisturbed field will have to be 3 dB less than in the frontal oncoming plane wave if it is to effect the same sound level in the tympanum, thereby creating the same loudness. More details with reference to this will be given in another study [7].

According to the foregoing results, the necessary level for 40 phons will be determined for the undisturbed comparative third-octave at 38 dB for the plane wave, and at 35 dB for the diffuse acoustic field. Furthermore, we can deduce therefrom that the curve measured in this study for a third-octave of 50 dB in the diffuse field will correspond to a loudness of 55 phons.

4. Conclusions and discussion of the results

For each measurement, the minima and maxima noted by the level recorder were represented graphically and coordinated with the frequency course of the probing apparatus. The arithmetic average of the results of all the n persons tested

$$\bar{L}_{oct} = \frac{\sum_{r=1}^n L_r}{n} \quad (1)$$

is shown in Fig. 2. above the frequencies of the bands. Further, in these curves the average error for the medium value is marked as a perpendicular stroke.

$$q = \pm \sqrt{\frac{\sum_{r=1}^n (L_r - \bar{L})^2}{n(n-1)}} \quad (2)$$

The 55-phon curve was tested on 6 persons. The two 40-phon curves give the average results for a group of 10 persons.

The octave-level curves L_{oct} here as well as in Fig. 4, at 1 kHz lie somewhat lower than the maintained constant level of the comparison-third L_{third} 1 kHz, since they cover several frequency groups.

At least in the vicinity of 1 kHz a level difference of

55 40 45 dB between both of the curves measured in the diffuse field is to be expected. This difference manifests itself with practically no change right up to the highest frequencies, even though the persons participating in the measurements were not entirely the same. It is only below 300 Hz that the 40-phon curve becomes a bit more steep than the 55-phon. But such behavior is also known for curves of equal-loudness for sine-tones in the plane wave.

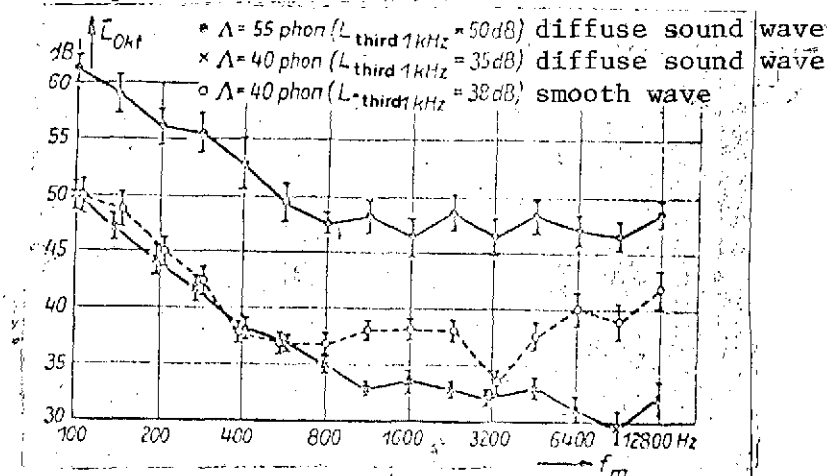


Fig. 2. Curves of equal-loudness for octave-bands.

We can assume from the two 40-phon curves that below 600 Hz, where there still are no essential acoustical field distortions due to the human head, the same sound level will always effect an identical loudness regardless of the form of the field. This would coincide with the result of our investigations already /189 referred to concerning the relationship of loudness and sound pressure on the tympanum [5].

The differences, however, of up to 7 dB in low frequencies between the curves of equal-loudness in the plane wave and in the diffuse acoustic field, measured by Plenge and Schwarze ([8], Reproduction 9) at the Institute for Research in Oscillations of the Berlin Technical University, and most curteously/ communicated to the author of this study, do not at all coincide.

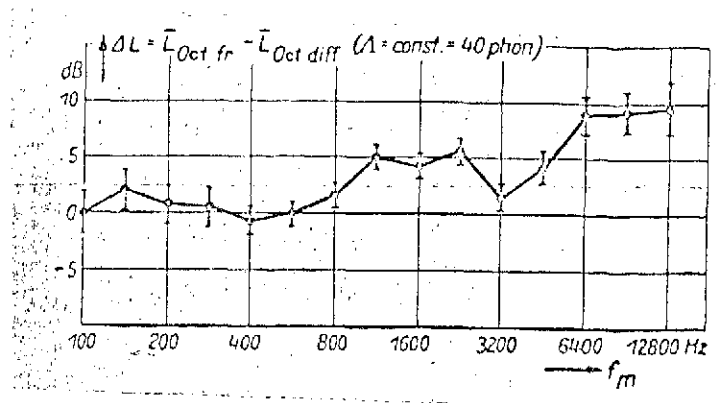


Fig. 3. Difference in curves of equal-loudness for the octave-band in the plane wave and in the diffuse acoustic field.

For higher frequencies, because of the curve of the sound at the head, one would expect the different course of the 40-phone curves measured in the two acoustic fields. Exact quantitative data on the difference between both these isophones cannot be given because of the relatively large spread of the results of subjective loudness comparison in the corresponding curves. The curve shown in Fig. 3, however, which represents this difference, coincides essentially with the preliminary findings of our objective measurements of this difference already referred to [7].

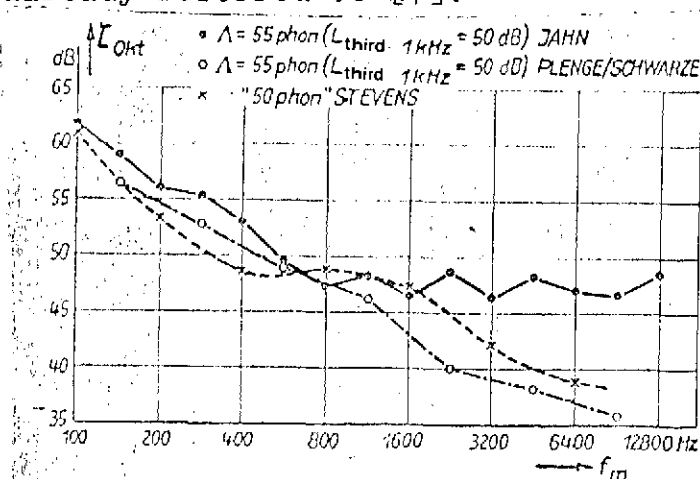


Fig. 4. Curves of equal-loudness for octave-bands in the diffuse acoustic field.

Figure 4 gives our 55 phon 50 dB curve together with the corresponding one of Plenge and Schwarze [8] and the 50 phon curve according to Stevens ([2], Fig. 18). It would be wrong to expect a complete agreement of the three curves, since the experiments were carried out on different test teams. Besides, some of the other conditions of the experiment were also quite different. The measurements undertaken by Stevens, for example, were made in "an ordinary room with acousticalotex on the ceiling", while for both the experiments made by us as well as for those of Plenge and Schwarze great importance was attached to bringing about the highest possible diffusiveness in the hall-room. Considering these differences together with some of the others, the slight discrepancies in the results are not surprising. One could ascribe to them as a maximum the difference of 5 dB in low frequencies. But it would be demanding too much to try to explain thereby also the differences of 10 dB above 2 kHz.

Because of these great differences it would seem to be a bit premature to consider one of these three curves as the correct one to be applied as the basis for calculations of loudness from the spectrum. It would first be necessary to make a more thorough investigation with a large group of people in an exact diffuse acoustic field. In that case special attention would have to be given to the question as to which loudness (corresponding to the definition according to [3] and [4]) the sound level of the chosen comparison signal should correspond, so that the measured curves can truly be identified with a loudness in phons. As far as we are informed, it is only in the present article that has been attempted. As Plenge and Schwarze were also aware of this, they used the term "noise level in dB" rather than loudness. With equal-loudness, however, this will depend on the properties of the acoustic field (whether diffuse

or frontal) and on the bandwidth of the comparison signal selected. Although not consistent with his later publications, [10] and the results of Zwicker and Fledtkeller [9] Stevens gives the sound level of an octave-width band of about 1 kHz in dB numerically equal to its loudness in phons. Such different treatment of the question of relative magnitude only complicates the comparison of the various results. It is to be hoped that in future investigation all the results concerning the binaurally heard sound level of the frontal incoming plane sine-wave are correctly coordinated by appropriate measurements.

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